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PAYLOAD ACOUSTIC NOISE CONTROL GUIDELINES

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PREFACE

ACKNOWLEDGMENTS:

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PAYLOAD ACOUSTIC NOISE CONTROL GUIDELINES

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1.0 INTRODUCTION

Excessive noise in the Orbiter and laboratory-pressurized modules interfere with crew communications, sleep, cause headaches, ringing of ears and can cause temporary hearing threshold shifts during short missions. Since payloads contribute to the overall noise level, it is important that noise mitigation be designed into the payload. To help the payload developers design quiet hardware, the ISS Payload Engineering Integration (PEI) office has developed an acoustics noise control guideline. This guideline outlines various noise mitigation concepts and presents previously successful techniques used to reduce noise.

1.1 SPACE STATION OVERVIEW

The International Space Station (ISS) is a microgravity laboratory in Low Earth Orbit. The ISS is of a modular design; new modules are developed, launched and attached to the ISS until the final stage, called Assembly Complete. As International Partners (IPs) modules are added, more facilities become available for installation and operation of scientific payloads. The United States Laboratory (US Lab) contains thirteen payload racks, the Japanese module eleven, the Columbus module eight, and the Centrifuge Accommodation Module six racks available for microgravity sciences, life sciences, space and earth sciences, commercial product development and engineering research/technology.

Figure 1.1-1, International Space Station Assembly shows the general arrangement of the ISS at Assembly Complete. The contributions from each IP are indicated in this representation.

Each pressurized module (except the Pressurized Mating Adapters) contains equipment which generates noise. One of the challenges of building the ISS is to ensure that acoustic noise levels meet requirements and do not pose a negative impact to crew health and performance on-orbit.

1.2 ISS PROGRAM ORGANIZATION OVERVIEW

The top level of the ISS program organization begins at the NASA Office of the Program Manager. The program manager office oversees the activity of various sub-tier organizations including the Payload Office. The NASA payload office is organized with six separate offices that support the research and payload programs. Each office has a separate but related function that supports the overall goals of the Program office.

OZ1 – ISS Research Program Managers

OZ2 – Payload Mission Integration and Planning

OZ3 – Payload Engineering Integration

OZ4 – Research Mission Management

OZ5 – Payload Software Integration

POIC - Payload Operation Integration Center

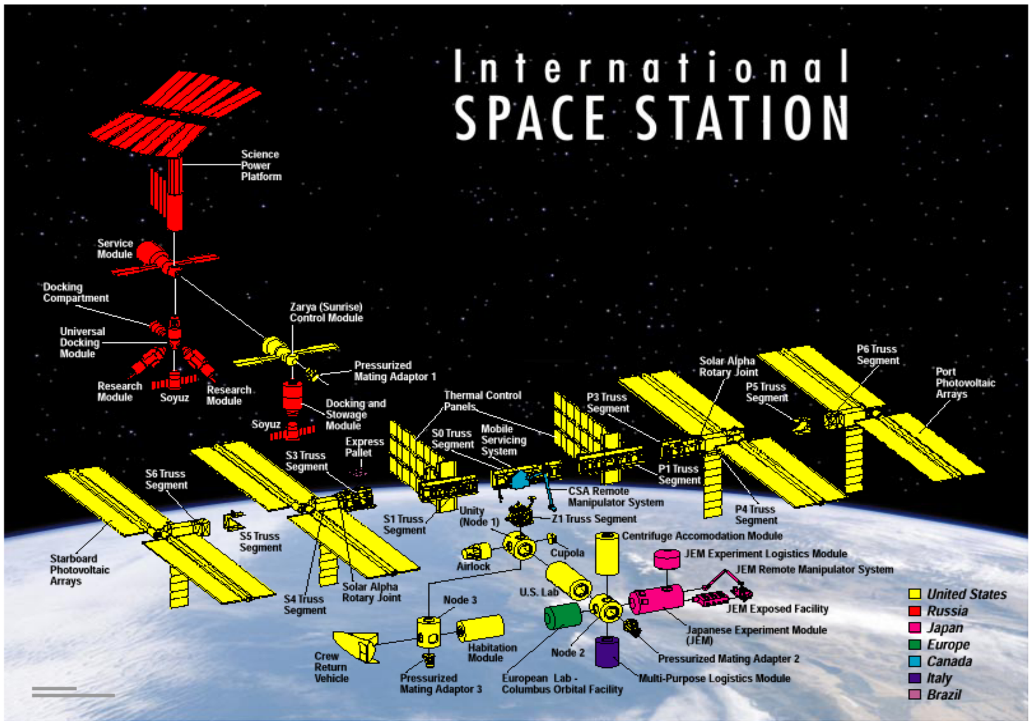


FIGURE 1.1-1 INTERNATIONAL SPACE STATION ASSEMBLY

1.3 BOEING ISS PAYLOAD INTEGRATION CONTRACT PAYLOAD ENGINEERING AND INTEGRATION ORGANIZATION AND CHARTER

The Boeing ISS Payload Integration Contract (IPIC) PEI organization works with the NASA Payload Office. The Boeing IPIC PEI manager oversees Payload Support Systems, Payload Software, Payload Engineering and Integration, Mission Integration, and the Payload Operations Integration Center. The PEI group is responsible for integration of payloads that are to be flown and installed in US-owned science facilities. This integration activity includes defining the interfaces between the payload rack and the ISS, stage analysis, operations, human factors, research accommodations and Certification of Flight Readiness (CoFR).

Acoustics is an important part of this integration activity. For example, noise requirements are included in all interface documentation. Stage analysis of acoustic noise levels is necessary to support operational guidelines/constraints development and CoFR.

1.4 ACOUSTIC WORKING GROUP

The Acoustic Working Group (AWG), chartered by the Habitability and Environmental Factors Office (HEFO) at Johnson Space Center (JSC), oversees on-orbit acoustics for the entire ISS, including vehicle subsystems, payloads and IPs. The AWG is co-chaired by the NASA Acoustics Office and Boeing. The AWG also has representation from the NASA Crew Office, Safety, ISS contractors and the NASA Flight Medicine Office. Acoustic issues and requirements enhancements are all coordinated as necessary through the AWG. The NASA and Boeing payload community relies on the AWG for direction and resolution of acoustics issues..

1.5 PROGRAM REVIEW PROCESS FOR ACOUSTIC NOISE

The IPIC PEI organization performs an overall acoustic assessment using module acoustic data from the vehicle subsystems and the noise contribution from all payloads. This analysis is performed for each stage. Each payload developer and rack integrator provides acoustic verification data, which is used as input to an analytical model of the module noise environment. RAYNOISE® ray-tracing software, from LMS International, is used for the acoustic modeling. The results are used to produce the acoustics section of the overall Element-Level Engineering Analysis Report. This report is used for safety analysis, for production of Operations Guidelines and Constraints document, and for final verification closeout as part of the CoFR.

1.5.1 ENGINEERING ANALYSIS REPORT

The acoustics section of the Payload Element-Level Engineering Analysis Report contains noise predictions for payloads at the element (e.g. US Lab) level for each Stage. Integrated rack noise levels are compared to their applicable rack-level requirements. The noise due to all payloads in an element is compared to the NC-48 complement level noise limit required by SSP 57011, Payload Verification Program Plan. In addition, overall noise levels due to all sources (vehicle plus payloads) are predicted for subsequent safety review and analysis. The results of the stage analysis help to determine if waivers or exceptions for individual payloads are acceptable or if operational constraints are advisable.

1.5.2 SAFETY ANALYSIS AND REVIEW

Payload non-compliance relating to acoustics is also documented in an Integrated Equipment Hazard Analysis (IEHA) by the Safety organization. The Payload Safety Review Panel (PSRP) subsequently reviews the IEHA. Maximum noise levels are examined from a hearing conservation and crew operational safety standpoint.

1.5.3 OPERATIONS GUIDELINES AND CONSTRAINTS

Time lining recommendations for noise control are contained in the Operations Guidelines and Constraints document for each Stage. The Engineering Analysis Report is the source of information for the Operations Guidelines and Constraints (GL&C) document. The GL&C document contains constraints on which racks or sub-racks may be operational at the same time and limits the total time each rack or sub-rack may operate within a 24-hour period.

1.5.4 VERIFICATION CLOSEOUT AND CERTIFICATION OF FLIGHT READINESS

If noise requirements are not met, the payload rack integrator is responsible for submitting acoustic exceptions. Any acoustic exceptions must be processed and approved prior to verification closeout and CoFR. Sub rack, rack-level, and element-level acoustic noise levels will be reviewed by the AWG. Final disposition is provided by the Program Integration Control Board (PICB) is needed for acoustic exceptions and the element level. All exceptions must be approved by the appropriate parties and must be incorporated into the appropriate hardware Interface Control Document (ICD) prior to CoFR.

2.0 APPLICABLE DOCUMENTS

SSP 41000 Revision AV March 2005	System Specification for the International Space Station Alpha
SSP 41160 Revision F June 2004	European Space Agency Segment Specification for Columbus
SSP 41162 Revision AR September 2004	Segment Specification for the United States On-Orbit
SSP 41163 Revision J October 1999	Russian Segment Specification
SSP 41165 Revision J July 2004	Segment Specification for Japanese Experiment Module
SSP 50290 Revision D January 2003	Prime Item Development Spec for Node 2
SSP 50312	NASA/NASDA Joint Specs for CAM
SSP 50318 Initial Release September 2004	Prime Item Development Spec for Node 3
SSP 50333 Revision D March 2003	Cupola Segment Specification
SSP 52000-IDD Revision E September 2003	Expedite the Processing of Experiments to Space Station (EXPRESS) Rack Payloads Interface Definition Document
SSP 57000 Revision G September 2003	Pressurized Payloads Interface Requirements Documents
SSP 57011 Revision B January 2003	Payload Verification Program Plan

S684-10102 Revision J November 2002	Prime Item Development Specification for Node 1
S684-10142 Revision M November 2002	Prime Item Development Specification for Airlock
S683-29523 Revision P August 2002	Prime Item Development Specification for United States Laboratory

2.1 REFERENCE DOCUMENTS

SSP 50431	Space Station Program Requirements for Payloads

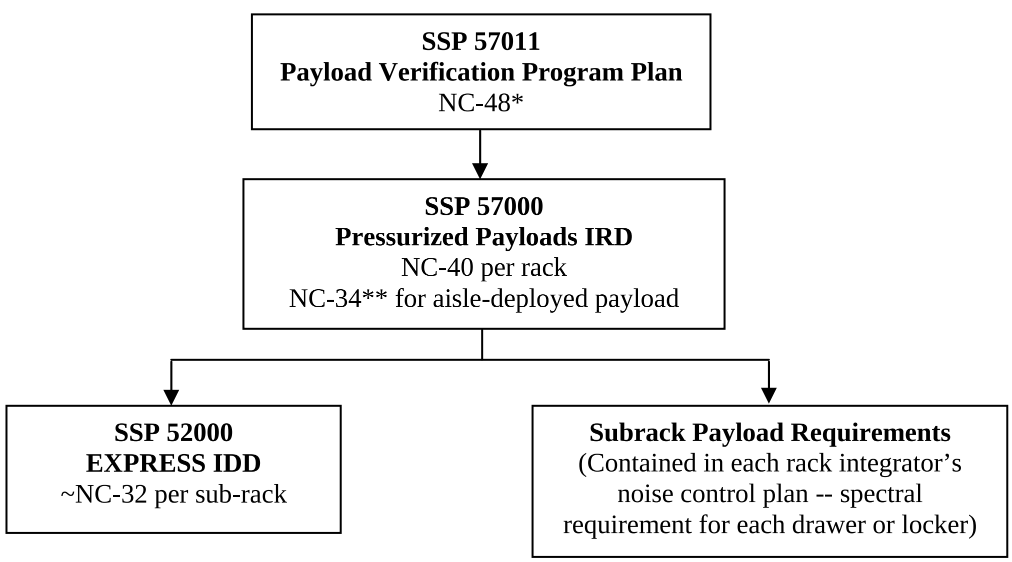
3.0 ISS ACOUSTIC NOISE REQUIREMENTS

The first step in any noise control program is to establish noise requirements for the end-item and subsystem equipment. The ISS program implements noise requirements at many levels, from the ISS vehicle end item, to the individual modules, to the system racks, and finally the scientific payload equipment that will be installed on-orbit.

ISS acoustic noise requirements are divided between vehicle and payload noise requirements. The vehicle requirements are levied upon the overall noise produced by the vehicle and all supporting subsystems that are not considered payloads. The vehicle is a platform to support payloads, and payloads are considered an external interface to the vehicle. Information on vehicle noise and requirement flow can be found in Section 10 of this guideline. Payload noise requirements start at the module level. These requirements are further sub allocated to the rack level, and then further sub-allocated to individual sub-rack payloads. An overall noise limit applies to the total noise level within a module due to all payloads in a particular payload complement.

3.1 PAYLOAD NOISE REQUIREMENTS

Payload noise requirements begin at the integrated module level and are then sub-allocated to a payload complement level. This is documented in SSP 57011. NC-48 is established as the Sound Pressure Level (SPL) complement for all continuously operating payload racks and aisle–deployable payloads within a single module. NC-48 is also applicable to International Partner modules. Figure 3.1-1, "Flow-Down" of ISS Payload Noise Requirements shows, in general, how payload noise requirements flow down from the top-level NC-48 criterion. If a payload rack does not use its entire noise allocation in each octave band, noise requirements for other racks may be relaxed such that NC-48 is still achieved within the module.



* NC-48 is the overall noise requirement applicable to the sum of all payloads in the complement for a specific ISS Stage or Increment.

** Assuming four payload racks and two aisle-deployable payloads active at the same time.

FIGURE 3.1-1 "FLOW-DOWN" OF ISS PAYLOAD NOISE REQUIREMENTS

3.1.1 RACK-LEVEL REQUIREMENTS

Requirements for integrated payload racks are contained in SSP 57000, Pressurized Payloads Interface Requirements Document (IRD). Acoustic noise limits are defined for two types of noise sources: (1) Continuous Noise Sources and (2) Intermittent Noise Sources. An integrated rack that operates for more than eight hours in a 24-hour period is a Continuous Noise Source. An integrated rack, which operates for eight hours or less in any one 24-hour period, is classified as an Intermittent Noise Source. If a payload rack exhibits both continuous and intermittent noise characteristics, then the cumulative time it generates noise above NC-40 during a 24-hour period should satisfy the rack-level intermittent noise requirements.

The continuous rack-level requirement for any individual integrated payload rack is NC-40, as measured 0.6 meters from the noisiest part of the rack front face. The NC-40 curve is put in tabular form below Table 3.1.1-1, Continuous Noise Limits for Payload Racks (NC-40).

TABLE 3.1.1-1 CONTINUOUS NOISE LIMITS FOR PAYLOAD RACKS (NC-40)

Rack Noise Limits Measured at 0.6 Meters from Noisiest Part of Rack Front Face	
Octave Band Center Frequency (Hz)	**Sound Pressure Level (dB)**
63	64.0
125	56.0
250	50.0
500	45.0
1000	41.0
2000	39.0
4000	38.0
8000	37.0

Intermittent noise is to be controlled to the limits below Table 3.1.1-2, Intermittent Noise Limits for an Integrated Rack in terms of A-weighted Overall Sound Pressure Level (dBA).

Acoustic noise limits provided in the IRD for individual integrated racks, are further sub-allocated to sub-rack components by the rack integrator. This is done so the acoustic noise of the integrated rack will not exceed NC-40. As is the case with a payload complement of racks, noise requirements on certain sub-rack payloads may be relaxed if other sub-rack payloads do not use their entire noise allocation.

TABLE 3.1.1-2 INTERMITTENT NOISE LIMITS FOR AN INTEGRATED RACK

Rack Noise Limits Measured at 0.6 Meters from Noisiest Part of Rack Front Face	
Maximum Noise Duration	**Overall A-Weighted Sound Pressure Level (dBA)**
< 8 hours	49.0
7 hours	50.0
6 hours	51.0
5 hours	52.0
4.5 hours	53.0
4 hours	54.0
3.5 hours	55.0
3 hours	57.0
2.5 hours	58.0
2 hours	60.0
1.5 Hours	62.0
1 hour	65.0
30 minutes	69.0
15 minutes	72.0
5 minutes	76.0
2 minutes	78.0
1 minute	79.0
Not Allowed	80.0

3.1.2 NON-RACK PAYLOAD REQUIREMENTS "AISLE-DEPLOYED PAYLOADS"

Acoustic noise limits of non-rack components, operated independently of, and outside an integrated rack, are not allocated the same limits imposed for an integrated rack (NC-40). To help control the noise environment due to all payloads, the noise limit for non-rack equipment is NC-34. Table 3.1.2-1, Continuous Noise Limits For Non-Rack Payloads (NC-34) below gives the maximum octave-band noise levels allowed by the NC-34 criterion.

TABLE 3.1.2-1 CONTINUOUS NOISE LIMITS FOR NON-RACK PAYLOADS (NC-34)

Rack Noise Limits Measured at 0.6 Meters from Surface of Equipment	
Octave Band Center Frequency (Hz)	**Sound Pressure Level (dB)**
63	59.4
125	52.1
250	45.0
500	39.0
1000	35.0
2000	33.0
4000	32.0
8000	31.0

Note that any external adjunct equipment that is operated in support of an integrated rack is included with the integrated rack noise limits.

4.0 ACOUSTIC NOISE CONSIDERATIONS FOR PAYLOAD HARDWARE

Once applicable noise requirements have been identified, an initial assessment of the payload-generated noise must be performed. The overall acoustic noise approach for payloads is to assess all individual noise sources. The initial assessment must then be verified using component tests or test results from the actual payload hardware. Actual hardware is needed due to variations that may result in hardware provided from the manufacturer (i.e. two identical fans may not have identical noise signatures, packaging of hardware may be different, and noise generated by flow paths may be different). Initial noise predictions may be made from qualification units, previously flown identical payloads or from similar payloads for which noise data exist. Even if the initial noise prediction indicates that noise requirements will be met, the payload must still be designed and built to ensure compliance.

It is important to understand when adding and subtracting noise sources that the dB be treated logarithmically. The addition of two identical sound levels in dB does not equal twice the first (50 dB + 50 dB does not equal 100dB). Instead, two incoherent levels A and B in dB must be added "logarithmically":

$$10 \times Log_{10}((10^{A/10}) + (10^{B/10}))$$

From the previous expression, if sources A and B were equal to 50 dB each, the result would be 53 dB when adding the two sources together (See Reference # 3, eq 1.19. All references are located in Appendix D of this document).

The acoustic noise design challenge can be broken down into three parts -- sources, transmission paths, and receivers. Since receivers consist of the international crew, acoustic noise control must first be considered for the sources and transmission paths. Reduction of noise levels at the source is the preferred method of noise control; the treatment of transmission paths is considered a secondary method. Noise control is most efficient when implemented at the beginning of hardware development. This is because design changes for noise control are easier and less costly to make during the preliminary design phase. Once hardware is built, the number of available noise control options becomes limited.

4.1 DESIGN CONSIDERATIONS TO MINIMIZE ACOUSTIC SOURCE NOISE

Mechanical systems involving moving parts (e.g., motors, pumps, and fans) or fluid flow ducts are usual sources for acoustic noise generation. Noise emission from these sources can be reduced through judicious selection of components and attention to the component installation details that affect noise generation and transmission. Even if a low-noise component is selected, the installation details should be carefully chosen since they can often cause more noise generation or create additional radiating surfaces.

4.1.1 FAN NOISE

Fans tend to be the primary noise sources within payloads, and so deserve special attention. In general, vane-axial or centrifugal fans with airfoil blades create lower acoustic levels than other fan types. Also, fan blades constructed from plastic material have been observed to be less noisy than blades made of metal.

Below is a listing of the potential sources of fan noise generation. The actual noise source mechanisms can be quite complicated, and only a cursory treatment is given here.

Blade Passage Tones

Blade passage tones are generated from fan blades sweeping past a point in space, causing acoustic pressure fluctuations. The frequency of the tone is computed from the rotational frequency, multiplied by the number of blades. Harmonics of the Blade Passage Frequency (BPF) are also created in whole number multiples of the BPF. The strengths of the tones are dependent on many factors, including blade pitch, blade profile and width. Tones that are created from the BPF are generally easier to control at higher frequencies with the use of open-cell foams. On the other hand, by controlling the airflow of the fan one can shift the tone into the lower frequencies where the requirements are less stringent.

Vortex Shedding

This is a broadband noise source generated by air separation from the blade surface and trailing edge. It can be controlled somewhat by good blade profile design, proper pitch angle and notched or serrated trailing blade edges. Fan speed can impact the amount of noise generated and can be reduced by a reduction in speed. Strong tones may be generated from blade-vortex interaction, when the following blade impinges on the vortex created from a leading blade.

Structural Vibration

This can be caused by the components and mechanism within the fan, such as residual unbalance or bearing noise. Motor mounting noise is difficult to predict, but it should be remembered that cooling fans are basically motors and should be suitably vibration-isolated.

Turbulence

Turbulence is created in the airflow stream itself. It contributes to broadband noise. Fan inlet and outlet disturbances, sharp edges and bends in ductwork will cause increased turbulence and noise. The placement of heat exchangers or finger-guard grilles too near the fan intake or exhaust often results in increased noise.

Fan Speed

The effect of fan speed on noise can best be seen through the following relation which follows directly from the rule of thumb that fan noise is proportional to speed to the 5th power:

$$SPL_2 = SPL_1 + 50 Log_{10}\left({}^{rpm_2}\!/_{rpm_1}\right)$$

Thus, fan speed is a major contributor to fan noise. For instance, if the speed of a fan is reduced by 20%, the noise level will be reduced by 5 dB.

Also, since flow rate is proportional to fan speed and Q_2/Q_1 is equal to rpm_2/rpm_1, the same noise level equation above may be written,

$$SPL_2 = SPL_1 + 50 Log_{10}\left({}^{Q_2}\!/_{Q_1}\right)$$

where,

SPL = Sound Pressure Level in dB

rpm = fan speed

Q = volume flow rate

Note the above equations may be used only for broadband noise; tonal noise is not predicted.

Fan Load

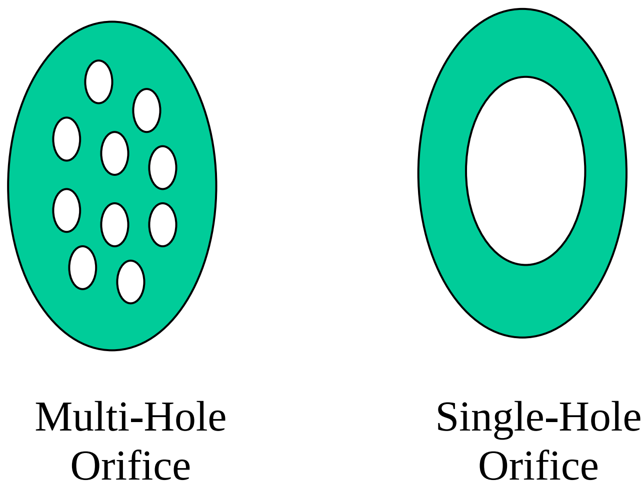
Noise varies as the duct system load varies. This variation is difficult to predict and fan dependent. However, fans are generally quietest when operated near their peak “static efficiency”. Historically, noise level changes have been seen in hardware as a result of a change in pressure that caused loading on the operating fan.

Additional information on fan noise can be found in Reference # 4.

4.1.2 DUCT SYSTEM NOISE

Acoustic noise emission from fluid ducts or piping can be reduced by designing for low flow velocities and by avoiding large pressure drops in the system. In general, ductwork should be designed to minimize turbulence. Turbulent flow tends to generate noise, and strong tones may be generated by flow separations.

When using flow control orifice plates, they should be multi-hole instead of single hole, as depicted in Figure 4.1.2-1, Low-Noise Multi-Hole Orifice Plate. Although, the NC-40 octave band requirement allows for greater noise in the lower frequencies, using a multi-hole orifice may alter or shift the noise to a higher frequency. Higher frequencies are generally easier to



control with the use of open cell acoustic foam. Refer to Reference #5.

FIGURE 4.1.2-1 LOW-NOISE MULTI-HOLE ORIFICE PLATE

Duct System Impedance (flow resistance)

The system flow resistance should be as low as possible. This will have two beneficial effects: More fluid flow will be obtained with lower pressure drop in the system, and smaller pressure drops generally generate less noise. An additional benefit is that smaller fans or pumps will be required resulting in less noise output from the fan or pump.

Flow Disturbance

Obstructions to the airflow should be avoided whenever possible, especially in critical fan inlet and outlet areas. When turbulent air enters a fan, strong fan tones may be generated which can cause considerable annoyance. In general, flow entering a fan should be as "clean" as possible, meaning straight and turbulence-free.

Fan Speed and Size

Multiple fan sizes should also be explored; quite often a larger, slower fan will be quieter than a smaller, faster fan delivering the same airflow. Typically, smaller fans need to rotate faster to achieve the same flow rate or produce a desired output. This will result in a higher frequency blade passage tone. One way around this is to select a larger fan that will rotate at a slower speed. This will reduce the overall noise and shift any blade pass tone to a lower frequency where ISS noise requirements are less stringent. The ideal situation is to obtain the required flow at the minimum fan speed and maintain the appropriate duct size that allows for minimum flow resistance.

The fan should be selected so that the intersection of the duct system resistance and the fan curve will result in the fan operating near its ideal operating point, as in Figure 4.1.2-2, Fan Operating Point. Special care should be taken to ensure each fan does not operate in its stall region. Stall sets in at the point where increasing flow resistance at fixed rpm causes the fan pressure rise to decrease instead of increase, as shown in Fig 4.1.2-2.

If possible, fans should be integrated with some additional space allocated for duct mufflers or an enclosure if needed.

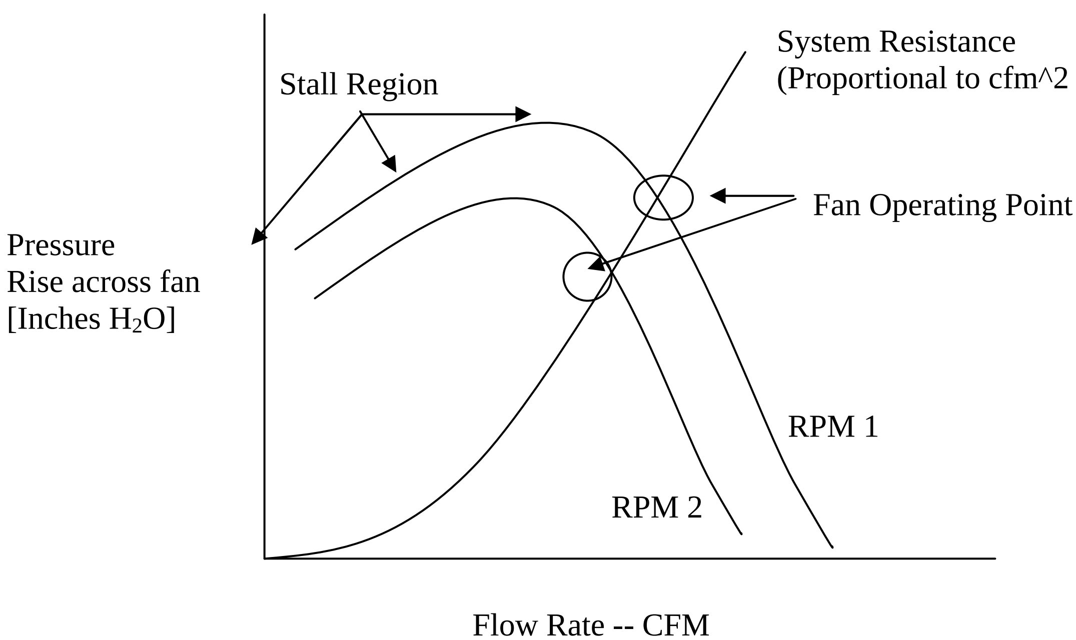


FIGURE 4.1.2-2 FAN OPERATING POINT

Vibration Isolation

Fans should be mechanically isolated from the mounting to avoid vibration transmission. If fans operate at a low rpm, and are light in weight, the vibration isolators must be very soft and flexible. An example material that is used is HT-800, found in the material selection table.

4.1.3 OTHER NOISE CONTROL CONSIDERATIONS

Power Transmission/Motion Control

Motion control and power transmission are often accomplished with the gears or chains. The meshing of metal gears or chains/sprockets may thus create noise. Alternate, quieter methods of motion and power transmission can be accomplished using flexible belts and/or low-noise gears.

Cooling Requirements and fan Speed Reduction

For acoustics, required airflow is roughly proportional to amount of cooling required for ISS. If the temperature limit or its allowable variation can be relaxed, a noise reduction may result. Limits that are more stringent than needed can cause fans to cycle more often and thus increase the total duration of the associated noise. For fans that run continuously, relaxation of temperature limits may allow the fan operating voltage (and thus the speed) to be lowered. Reducing fan speed to the minimum level required can significantly reduce noise emission. A guideline for selecting the proper airflow for cooling is listed below as derived from the mass flow equation:

$$\dot{m} = {dm}/{dt} = cfm \times \rho$$

$$\rho = density$$

and the heat flow equation

$\dot{Q}$ (Power) = Energy/time = $\dot{m}$ x c ΔT

By incorporating conversion factors and the specific heat and density of air, the following rule of thumb is derived.

CFM Cooling Prediction

CFM = 3.16 x Watts/Allowable temperature rise

CFM = Flow in cubic feet per minute

Watts = Amount of energy to dissipate

Allowable temperature rise = Change in temperature in degrees F

31.6 cfm of air impinging on a black box emitting 100 Watts of heat would have its effluent airflow raised by 10 degrees F

This yields a rough estimate of the airflow needed to dissipate a given amount of heat at sea level. It should be noted that the mass of air, not its volume, governs the amount of cooling.

Assumptions and conversions are from Reference # 8.

Alternate Cooling Methods

The use of fans for cooling may be avoided by using heat sinks, cold plates or thermoelectric devices. Fluid cooling is more efficient and may eliminate the noise associated with fans.

4.2 DESIGN CONSIDERATIONS FOR CONTROL OF NOISE TRANSMISSION

Noise transmission may occur through two mechanisms: structure-borne and airborne. Complex situations may arise where airborne noise is propagated by structure-borne vibration and re-radiated into airspace.

Structure-Borne Noise Transmission

The first order of reducing structure-borne acoustic noise transmission is to isolate noise-source components and any associated piping or ducting from their structural support. The second most important item is to design support structures to avoid problem resonance by modifying structural stiffness, damping or mass. Problem resonance can occur in the form of local panel vibration modes, piping or ductwork vibration modes, or even primary structure vibration modes.

When problem resonance cannot be avoided, damping treatments may be effective. Damping treatments are applied to surfaces of structural members or panels. Damping treatment of a structure can range from simple thin coatings of viscoelastic materials to multi-layered constrained layer treatments. Figure 4.2-1, Viscoelastic Damping Treatment of a Structure (from Reference # 6) shows how a constrained layer treatment works to attenuate bending waves in structure. The structural waves induce shear strain in the viscoelastic material and therefore some of the energy in the wave is dissipated as heat in the viscoelastic. Figure 4.2-2, Reduction of Resonant Response Due To Damping Treatment shows schematically how the panel response can change with the addition of damping. The resonant peaks in the response are reduced. Note that this level of damping may be difficult to achieve in the real world.

Visco-elastic damping tape is a specific case of constrained layer damping; examples of materials that can be used are Iso-Damp C3201 and 3M Damping Tape. For more information on surface damping treatments and constrained layer damping, see References # 10, 11, and 12.

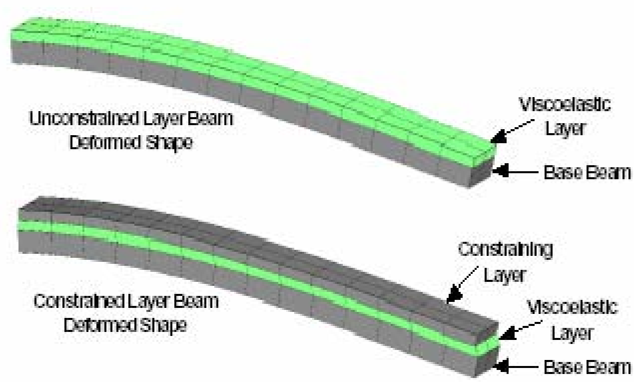


FIGURE 4.2-1 VISCOELASTIC DAMPING TREATMENT OF A STRUCTURE (FROM REFERENCE # 6)

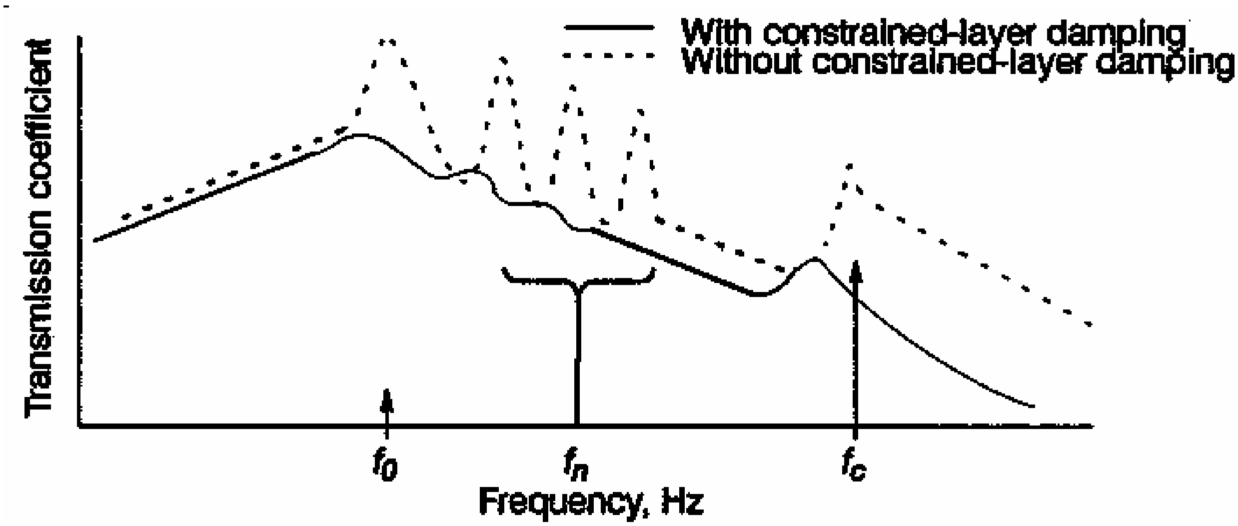


FIGURE 4.2-2 REDUCTION OF RESONANT RESPONSE DUE TO DAMPING TREATMENT

Airborne Noise Transmission

Airborne noise transmission from payloads aboard the ISS can be controlled by enclosing the source, modifying ducts and interior spaces, or moving the source as far as possible from habitable areas. As an example of the latter, if the front surface of a rack is exposed to a habitable area, locate the noise source at the rear of the rack. This results in longer transmission paths and therefore, more loss of energy. Sound Pressure falls off at a rate of (1 / distance^2). For a spherically symmetric noise source this can also be expressed by:

$$SPL = PWL + 10 \times Log_{10}\left(1 \big/ 4\Pi r^2 \right)$$

Where

SPL = Sound Pressure Level = dB

PWL = Sound Power Level = dB

r = distance = meters

A properly designed structure to enclose an acoustic source inherently attenuates the noise transmitted outside the enclosure. Enclosures designed to attenuate acoustic noise should include attention to many details, including stiffener placement, penetrations, enclosure isolation, and interior geometry. Rib-stiffened panels should be used carefully since sound tends to radiate from structural discontinuities in a panel, such as a panel-stiffener interface. Penetrations in enclosures for cables or pipes should be kept to a minimum. Penetrating pipes or cables should be as flexible as possible to avoid creating “flanking” paths. The enclosure itself should be mechanically isolated from internal noise sources if possible.

Adding absorptive liner materials within an enclosure increases acoustic absorption within the enclosure, thus, reducing acoustic energy and noise. Also, minimizing the radiation efficiency of the enclosure controls re-radiation of noise from the enclosure. This can be accomplished by avoidance of resonance frequencies and through the use of damping treatments.

Air ducts can be significant noise transmission paths. Constructing air ducts with internal absorptive material or mufflers can control propagation of noise along the duct. Since sound can propagate upstream and downstream in the duct, both upstream and downstream ductwork should be treated as appropriate.

Airborne noise also is generated at diffusers and grilles. Lowering airflow velocity reduces this effect. High relative airflow velocities should be avoided in mixing zones where air streams enter regions of relatively still air. More information on airborne noise can be found in Reference # 9.

Equipment Location

In general, noise-generating equipment should be placed as far away as possible from the noise receiver (crew member). For example, payloads that exchange air with the crew workspace should be avoided. Also, vibration and noise-producing equipment should be placed as far outboard as possible. Since noise levels are reduced as a function of distance from the source, this will reduce the noise environment at a given point.

4.3 MATERIAL SELECTION

Flight Approved Noise Control Materials

The following materials in Table 4.3-1, Flight Approved Material Used for Noise Control may be considered for use in controlling noise within payloads. Although all the materials are flight-qualified, the acceptability of any material will depend on its specific application. For instance, the total amount of Velcro used in the ISS module is limited. More information on the products can be obtained through the NASA Materials and Processes Technical Information System (MAPTIS) system using the referenced MAPTIS code.

Each material listed below has been qualified for a particular application and operating environment. Use of one or more of these materials must be approved by NASA Materials and Processes Labs for the particular application.

TABLE 4.3-1 FLIGHT APPROVED MATERIAL USED FOR NOISE CONTROL

MATERIAL	PRODUCT DESIGNATION	SOURCE	MATERIAL PROPERTY / USAGE	MAPTIS CODE
Polyimide Foam	Solimide HT340 (1)	Imi-Tech	Sound Absorption	03612
Polyimide Foam	Solimide AC406	Imi-Tech	Sound Absorption	88764
Polyimide Foam	Solimide TA301	Imi-Tech	Sound Absorption	62322
Polyimide Foam	Soundfoam HT	Soundcoat	Sound Absorption	85481
Constrained Layer Foam Damping Material	Iso-Damp C3201	E.A.R (Cabot Corp.)	Visco-Elastic structural damping material	02461and / or 04565
Metal Felt	Feltmetal FM-1812	Technetics	Sound Absorption or Duct Lining	10431(CRES 300)
Bisco (2 & 3) without fiberglass	HT-200	Rogers Corporation	Acoustic Barrier	04131
Bisco with fiberglass backing (2 & 3)	HT-200	Rogers Corporation	Acoustic Barrier	00179
Bisco gasketing	HT-800	Rogers Corporation	Visco-elastic damping gasket	00183
Nomex Blue	60650	Noah Lamport, Inc.	Foam Encapsulation	04878
Nomex White	HT-90-40	Stern & Stern Industries	Foam Encapsulation	06362
Durette Nomex Felt	F400-11	Fire Safe Products	Sound Absorption	06294
Melamine Foam (5)	Melamine or Willtec	Illbruck	Sound Absorption	00243
Hook 'n Loop Fastener	Velcro		Fastener for Acoustic Panels	63277
Thread	MIL-T-43636	Eddington Thread mfg	For sewing fabric around foam	01596
Adhesive Tape	PPP-T-66 Scotch 471 (4)	3M	For wrapping Bisco and sealing cracks	20945
Adhesive Tape	KPT-2 Kapton 1mil polyimide tape	www.kaptontape.com	Sealing fiberglass backing on Bisco	TBD
Adhesive Tape	Blue Flashbreaker Tape 4148	Great American Tape Company	All purpose, good for sticking to aluminum surface	86665
Adhesive Tape	Silicone glass tape 3M-361	3M	Wrapping and sealing cracks when using Bisco as a barrier	06188
Damping Tape	Damping Foil 2552	3M	Used for structural damping.	04869
Strip-N-Stick	100-S	Saint-Gobain Performance Plastics formerly Furon	Gasket material and vibration damping	62352

(1) All uses of Solimide Foam must either be encapsulated in a Nomex Blanket or otherwise treated to prevent flaking. This particulate problem has resulted in Melamine foam being the foam of choice for the ISS, but even melamine has flaking concerns when used in an area that will be exposed to extensive handling. (See also Note (5).
(2) BISCO = Barium Impregnated Silicon. BISCO is available in various densities from 0.25 lbs/ft^2 to 1.50 lbs/ft^2.
(3) The fiberglass backing on Bisco is available to provide structural integrity (to prevent tearing). Bisco without fiberglass is delivered with a Mylar backing, intended to be pealed off like a decal. This Mylar backing can substitute for the fiberglass to give structural integrity, as was done during the US Lab and Airlock acoustic tests to simulate rack closeouts.
(4) Although Scotch 471 tape may not stick to Bisco very well, it sticks to its own back, and is effective if wrapped completely around and fastened back to itself.

(5) Melamine foam is currently being evaluated on the levels of Formaldehyde that is off gassed from the foam. It is currently suggested that Melamine only be used if Solimide cannot.

4.4 OPERATIONAL CONSIDERATIONS FOR NOISE CONTROL

Noise within an ISS module may be controlled to some degree by choosing payload operational scenarios and conditions that minimize total noise output. For example, rescheduling science operations to prevent two (or more) noisy hardware items from operating simultaneously will result in reduced overall noise levels. If possible, timeline schedules should be developed for payload operation with respect to noise emissions. Operational constraints are developed by the PEI office and are provided to the Payload Operations Integration Center (POIC) to allow for scheduling of overall module operations to minimize acoustic noise.

5.0 EVALUATION AND VERIFICATION OF ACOUSTIC NOISE

Evaluation of noise output is needed as early as possible in the design phase or preliminary design phase of payload production. The earlier that noise is evaluated, the easier it will be to incorporate design features to minimize noise. Early assessment might include estimates based on noise output of similar payloads or on test data from development or qualification units.

5.1 VERIFICATION DATA VIA ACOUSTIC NOISE TESTING

The objective of acoustic noise testing is to determine the noise emission characteristics of an integrated rack (or subrack payload) during assent, on-orbit, and decent operational modes. The integrity of acoustic data is highly dependent upon the details of the acoustic test set-up and data acquisition methods. An improperly performed test provides data that can be misleading when used to determine the integrated module acoustic noise environment. This section provides general guidelines for performance of acoustic noise testing. If possible, trained or experienced personnel should operate the acoustic test equipment.

SPL tests provide the standard type of data required for verification. Sound Power Level (PWL) testing is no longer required in SSP 57000.

5.1.1 SOUND PRESSURE LEVEL (SPL) TESTING

SPL testing is the easiest way to quantitatively determine the noise characteristics of noise-producing equipment. Results of testing are more reliable than using analytical methods to evaluate noise. The guidelines below may be used for test preparation and test conduct to help ensure the data obtained are accurate and reliable.

Selection of Test Facility

When possible, noise tests should be performed in an anechoic chamber. An anechoic chamber is a room where boundaries are highly absorbent and the free-field region (i.e., region free of reverberation) extends almost to the absorbent boundary. The chamber is “Hemi-anechoic” if the floor is hard and the other surfaces are highly absorbent. One advantage of the anechoic or hemi-anechoic chamber test method is that a more complete definition of the noise emission field. Extraneous noise that may contaminate a measurement can usually be reduced when measured in a full or hemi anechoic environment. In an anechoic and hemi-anechoic chamber, it is easier to obtain additional measurements including both total sound power and sound directivity characteristics. However, sound power and directivity are not required for verification.

The background noise of a test facility should be at least 10 dB below the noise limits specified for the test article (i.e., the limits discussed in Section 3 herein). If this background noise level cannot be achieved, it is suggested that noise levels with the equipment operating be at least -6 dB greater than the background noise levels in effort to acquire accurate, non-contaminated data. In this case, background noise levels must be subtracted from the measured payload noise to obtain the true payload noise.

When subtracting background noise from the measurement, the following equations can be used,

$$10 \times Log_{10}((10^{A/10}) - (10^{B/10}))$$

In Fortran:

```
If (A .gt. B) then
A_corrected=10.*alog10 (10. ** (A/10)-10. ** (B/10))
else
A_corrected =B-10.
end if
```

In Excel format

=If (A<=B, B-10, 10*Log10(10^(A/10) - 10^(B/10)))

If |A-B| is not more than 6dB, then the method gives an upper bound on the noise.

This method has been the standard on the ISS program and is derived from the method in Reference # 7, which would also be acceptable.

It advises taking A_corrected = A-1.3dB for |A-B| < 6dB.

If an anechoic chamber is not available, test room dimensions should be as large as possible and the inner surfaces of the walls, floor, and ceiling should be as acoustically absorbent as possible. Acoustically reflective articles (e.g., bookcases, tables, filing cabinets) should be removed from the room or placed as far away from the test article as possible.

For many laboratory environments, steps to reduce the background noise may be required, such as turning off air conditioning equipment and/or using sound absorbing partitions to create a better background environment.

Payload Ground Support Equipment (GSE) that produces noise should be well separated from the flight hardware during testing (preferably located outside the test facility). If the GSE is in the test area, it should be operating during the background noise measurements.

Test Operation

The first test is to measure and record the background noise. This will verify that the background noise levels recommended in Section 5.1.1 are met. Background noise data shall be measured in each of eight octave bands: 63 Hz, 125 Hz, 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz, and 8000 Hz.

Noise tests should be performed with the test article configured and operated in all operational modes as defined by the Hardware ICD that will occur on on-orbit and will result in significant noise emission. Significant noise emission is defined as a noise source that produces a Sound Pressure Level of 37dBA or greater.

Integrated rack-level tests should obtain sound pressure levels on all sides of the rack. Verification for an integrated rack facility is to be measured at the noisiest point of the rack surface that is directly exposed to the habitable volume, at a distance of 0.6 meters as required by SSP 57000. Tests of sub-rack payloads should also obtain measurements at the loudest location, 0.6 meters from all sides of the operating payload.

(1) With the test article operating in a flight configuration, measure the A-weighted overall acoustic emission around all outer surfaces at 0.6 meter from the surface to locate the loudest point on each surface. For integrated rack tests, only the noisiest location on the rack front face needs to be located.

(2) Record acoustic noise emission from the noisiest point on each surface at 0.6 meter from the surface. If the noise source is continuous-type, operating for 8 or more hours per a single 24 hour period, SPL data shall be recorded in each of eight octave bands: 63 Hz, 125 Hz, 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz, and 8000 Hz. Verification of each rack (and adjunct equipment) is based upon the noisiest location on a surface adjacent to the crew environment. This data should be measured using linear (no weighting or filtering) response. If the noise source is intermittent-type, only the A-weighted overall SPL is required. However, octave-band data may be useful for intermittent sources in order to process any proposed exceptions.

5.2 VERIFICATION DATA BY ANALYSIS

Acoustic analysis may be used for preliminary verification and for final verification of integrated racks where it is not feasible to perform acoustic noise tests of an integrated rack. The output of the analysis should predict the noise contribution to the crew environment for each surface that is exposed to the habitable volume. The analysis and input data should be sufficiently detailed such that alterations of the configuration could be predicted within a defined level of tolerance. To account for possible error tolerance, the design goal for the integrated rack acoustic noise emission should be set at a value below the requirement (-3 dB for example).

When analysis is used to produce verification data, the analysis for the integrated rack shall be performed using a test-correlated analytical model or some other test-verified methodology as required by SSP 57000. Figure 4.3.12.3.3.1-1 of SSP 57000 provides a typical process for developing a test-correlated model. One approach to using this process would be to analytically compute/combine the emitted sound pressure levels from the various noise sources, and then applying noise attenuation and directivity factors as applicable to the integrated rack. Such an approach would require test correlation of the noise attenuation characteristics of the rack and test correlation of the effects of the integrated rack on directivity of the noise from the various noise sources. The Acoustic Working Group should be consulted for the approval of any test correlated acoustic model.

6.0 NOISE CONTROL PLANNING AND VERIFICATION REPORTING

The first stage of the acoustic integration process should begin at the start of hardware design development. Many times, hardware developers do not address acoustic noise requirements until the verification-testing phase. This is likely to result in hardware that will not meet noise requirements.

The second stage of verification is the planning and development of a Payload-Unique Acoustic Noise Control Plan for the integrated rack and ancillary equipment. The Acoustic Noise Control Plan should provide the payload integrator's plan for controlling acoustic noise emissions such that final verification requirements will be met. Noise control plans should be submitted as part of the Preliminary Design Review/Critical Design Review (PDR/CDR) data packages.

The third stage of verification is the submittal of a final noise verification report for flight certification that shows noise requirements have been met. Information submitted in the final Acoustic Analysis Report includes acoustic noise sources, noise emission from the integrated rack (or adjunct equipment), tests performed to measure noise emissions, analytical procedures used in deriving noise emissions, and compatibility with acoustic requirements.

6.1 VERIFICATION DATA REQUIREMENTS / SCHEDULE

Figure 6.1-1, Verification Data Requirements/Schedule below shows the generic schedule for acoustic data submittals as required by SSP 57057 ISS Payload Integration Template. The acoustic noise control plan and acoustic verification report submittals are required of the integrated payload rack developer. These are in turn used by the PEI organization to produce the element-level Stage Analysis, Guidelines and Constraints and the complete Verification Report, which is used to ensure all payload integration requirements are met.

6.1.1 INTEGRATED PAYLOAD RACK-UNIQUE ACOUSTIC NOISE CONTROL PLAN SUBMITTAL

The first report to be submitted is a Payload-Unique Acoustic Noise Control Plan, required at PDR and CDR. The Payload-Unique Acoustic Noise Control Plan defines the rack integrator's (or adjunct equipment supplier's) plan for ensuring/verifying that the integrated rack or adjunct equipment will meet acoustic noise requirements. The plan should describe the acoustic noise source(s), define applicable requirements, define the methodology for sub-allocation of requirements, identify the technical approach to verification (e.g., testing, analysis), describe the approach to validating analytical methods (if applicable), describe testing methodology, etc.

The plan should also identify the process that will be used to control acoustic noise of subrack elements. This includes a recovery plan that will be implemented if acoustic noise emissions exceed allocated noise requirements.

6.1.2 FINAL ACOUSTIC VERIFICATION REPORT

The second report to be submitted, required at L-9.5 for Expedite the Processing of Experiments to the Space Station (EXPRESS) Subrack payloads and L-7.5 for Integrated Facilities, is the Final Acoustic Verification Report. This report will (1) verify that the integrated rack or adjunct equipment meets acoustic requirements in the IRD, and (2) provide data that can be used by the Element Integrator to perform a final acoustic analysis of the integrated module.

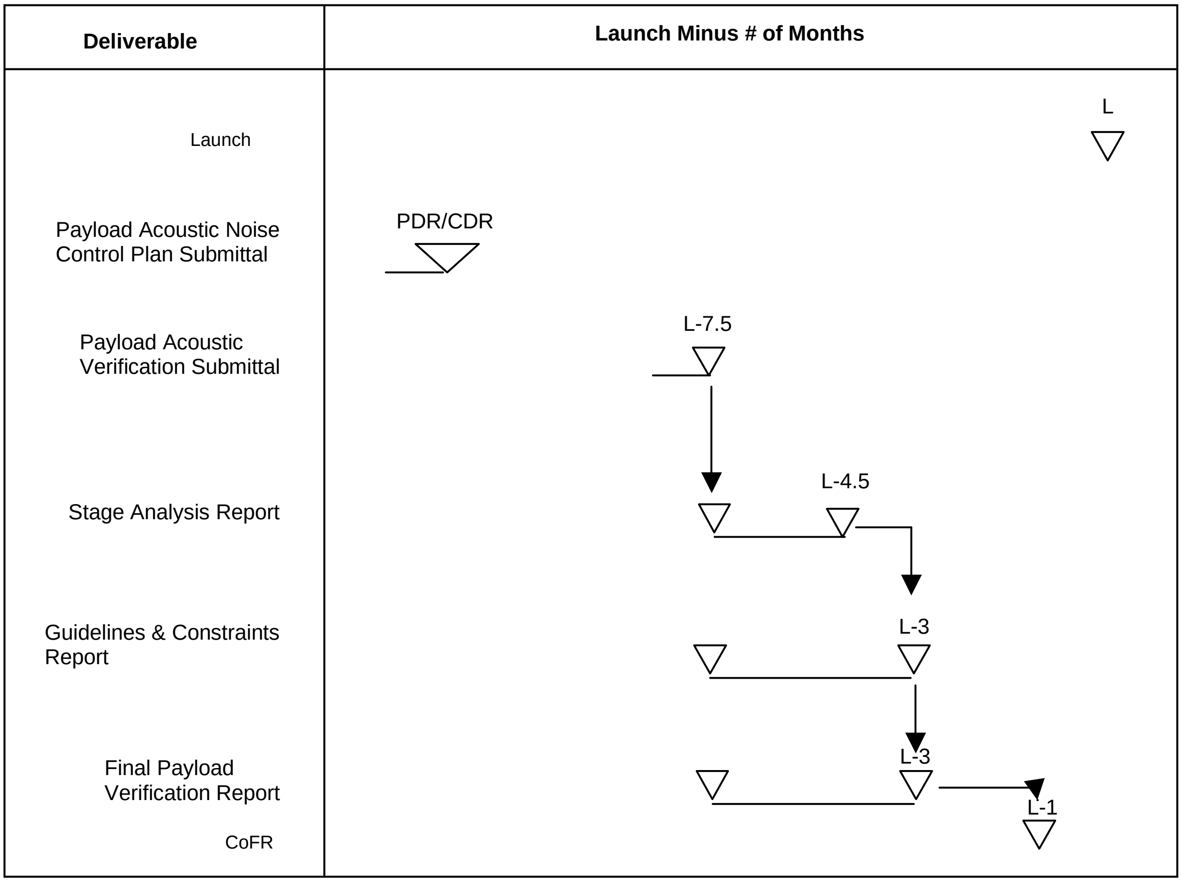


FIGURE 6.1-1 VERIFICATION DATA REQUIREMENTS/SCHEDULE

The Final Acoustic Verification Report should identify significant noise sources by type of noise (continuous or intermittent); provide the geometric location of noise sources; and provide SPL data for each noise source and operational mode. Operational data such as time-line schedules for each significant noise source shall also be provided in the report. A list shall be provided with data identifying independently operated equipment, dependent hardware, and adjunct hardware. Data shall be in sufficient detail to allow definition of the major noise contributors (e.g., data shall be provided for individual subrack elements within an integrated rack).

Payloads using the Vacuum Exhaust System (VES) shall list their exhaust requirements in terms of volume to be vented, initial pressure and outlet pipe diameter. The vacuum event information shall also include a description of how the vacuum exhaust events are to be time-lined; i.e., whether they correspond to crew activity, or are based upon self-activation or tele-science activities. Additional information on predicting VES noise as a function of payload exhaust gas, pressure, and volume can be found in Reference # 14.

The Final Acoustic Verification Report also shall provide information about the process used to obtain final verification data. Acoustic noise testing is the preferred method of obtaining final verification data, but in some cases, a test-verified analytical method must be used. (See Section 4.2) Information to be included in the Final Acoustic Verification Report is described below for each of the two methods of obtaining data. If acoustic data in the final report are obtained via testing, the report shall include the following:

(1) <u>Test Set-Up/Test Room Characteristics</u> – Describe (preferably via sketches and/or

photography) the test set-up including the type of room used in performing the tests. This should include a description of the test configuration including room dimensions, description of room surfaces, test article layout, equipment location and microphone locations.

(2) Acoustic Noise Emission Data – SPL data shall be provided for the loudest point (highest A-weighted sound level) on the front side of the integrated rack or for all sides of adjunct equipment. This information shall be provided for each operational mode for which acoustic data are collected. SPL data for continuous noise sources shall be measured at the octave-band frequencies: 63 Hz, 125 Hz, 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz, and 8000 Hz. The linear overall and A-weighted overall readings should also be provided. Data for intermittent noise sources shall be the A-weighted overall readings, with octave band data also reported if available. A type 1 sound level meter or better is required for these measurements.

(3) Background Noise Measurement Data – Background noise measurement data for each measurement point in Item 2 above should be provided.

If SPL data is obtained using a test-verified analytical method, the technical approach shall be documented in the report. The report shall also describe how the analytical method is test-validated. Data shall be provided for each operational mode identified. For continuous noise sources, the data shall include SPL data as a function of octave-band frequencies: 63 Hz, 125 Hz, 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz, and 8000 Hz. The linear overall and A-weighted overall levels should also be provided. Data for intermittent noise sources shall be the A-weighted overall levels, with the corresponding octave-band data reported if available.

6.2 GUIDELINES FOR DEVELOPMENT OF A PAYLOAD-UNIQUE NOISE CONTROL PLAN

As defined in Section 6.2.1, the payload developer is required to develop and submit a Payload-Unique Acoustic Noise Control Plan (ANCP). The ANCP is a product documented in SSP 50431 Space Station Program Requirements for Payloads, Table F-1 Generic Data Product List for ISS Payload Projects. Guidelines are provided in the following subsections for development of the information required in the plan.

Note that Express subrack payloads are no longer required to submit an Acoustic Noise Control Plan.

6.2.1 TECHNICAL CONTENT

The plan should define the approach that the payload developer will take to ensure/verify that the integrated rack or adjunct equipment meets acoustic noise requirements. In general, the plan will describe the system in terms of noise sources, applicable requirements, sub-allocation of requirements, how verification data will be obtained, how the data will be documented, and describe the general process for controlling noise.

System Description

The payloads that are covered by the plan should be described. Figures should be provided if possible, particularly for integrated-rack systems. The description should define the sub-elements comprising the payload and the type of noise emitted for the sub-element hardware (i.e., continuous or intermittent).

Requirements Definitions

The noise control plan should define the applicable acoustic noise limits to be used in hardware design/development and imposed as verification requirements. These noise limits include the applicable requirements from SP 57000, as well as those levied on sub-rack payloads.

Method for Obtaining Verification Data

One of the most important requirements for the contents of the plan is to define how data for final verification will be obtained (i.e., acoustic noise testing, acoustic analysis). Acoustic noise testing is the preferred method of obtaining final verification data. This includes acoustic testing of an integrated rack operating in its worst-case on-orbit acoustic noise configuration. In some situations, acoustic testing of an on-orbit configuration may not be possible. (For example, when subrack payload equipment will be changed out on-orbit.) In such cases acoustic analysis may be used to analytically combine acoustic data measured for subrack equipment. The analysis process, however, shall be test-validated as called out in SSP 57000.

If acoustic noise data is to be obtained by acoustic noise emission testing, the Payload-Unique Acoustic Noise Control Plan should describe the acoustic testing process. The description should include:

(1) Description of test facility. Includes type of facility (e.g., anechoic room), dimensions of test room, and acoustic properties of test room. (If test facility information is unknown, a description of the requirements that will be levied for the test facility can be described in lieu of the test facility description).

(2) Description of test article configuration. This should define all of the on-orbit configurations for the test article(s) that generate significant noise, identify which of the configurations will be tested, and provide rationale or selection process if not all are selected for test.

(3) Summary of the Acoustic Noise Test Plan/Procedure. This should provide the basic approach of how testing will be performed, where measurements will be made, and a description of the data that will be measured.

(4) Identification of data acquisition equipment. Includes a specification of acoustic noise measuring equipment that will be used for tests (or a description of requirements that will be levied).

Section 4.3.12.3.3 of SSP 57000 requires test-correlation of any analytical process used to obtained acoustic verification data. This includes test-correlation of acoustic analysis models or other approved analysis methods.

If a test-validated analytical process is to be used to obtain integrated rack acoustic noise emission using measured data for subrack equipment, the Payload-Unique Acoustic Noise Control Plan shall define the analytical process that will be used. The description of the analysis method shall discuss the technical approach and describe the process of test-validation for the approach.

Reporting Process

To ensure that preliminary and final acoustic noise data will meet the needs of the Element Integrator, the Payload-Unique Verification Plan should include a description and format of data that will be included in the Acoustic Noise Verification Report.

Noise Control Recovery Plan

Another aspect of the Acoustic Noise Control Plan is the payload developer's recovery plan if acoustic noise emissions exceed specified limits.

The following are typical examples of steps that could be implemented and described in a recovery plan.

(1) Modify Equipment to Reduce Acoustic Noise Emitted – Discuss possible equipment design modifications that could be implemented to reduce noise.

(2) Limit Number of Sub-rack Components Operating Simultaneously.

(3) Change Equipment Operational Parameters – Examples include change of equipment operating speed, change in operating voltage, etc.

(4) Implement Controls with Individual Equipment Developers – At the integrated rack level, one method of noise control is to determine significant contributors to the acoustic noise violation and, as rack integrator, work individually with the equipment developer(s) to reduce noise emission.

(5) Remove Conservatism using Higher-Fidelity Data – If acoustic noise data is preliminary data incorporating a factor of safety, an early testing program can remove unnecessary conservatism, thus reducing the predicted noise emission.

(6) Retrofit Acoustic Barriers to Experiments – Acoustic noise can be reduced by attaching an acoustic blanket or acoustic barrier to the front of the equipment or rack to absorb/block emitted acoustic energy.

(7) Reconfigure Integrated Rack to Remove Noisy Equipment.

(8) Use External Mufflers to Reduce Noise of "Front-Breathers.

6.2.2 APPROVAL PROCESS

The Payload-Unique Acoustic Noise Control Plan shall be submitted with each PDR/CDR data package (see SSP 50431, Table F-1, Generic Data Product List for ISS Payload Projects). The PEI and the Acoustics Working Group will review the plan to ensure the noise control and verification plans are adequate to meet the noise requirements in SSP 57000 and the data needs of the Element Integrator.

7.0 PREVIOUSLY SUCCESSFUL NOISE MITIGATION

The mitigation efforts documented within this section provide information on previously successful noise mitigation techniques that have been implemented on hardware that has flown and is currently flying on-board the International Space Station. Mitigation efforts do not guarantee compliance with acoustic requirements but are addressed as guidelines. A brief overview of mitigation techniques will be described.

For US Lab system racks' acoustic treatment, Reference # 13.

7.1 HUMAN RESEARCH FACILITY

The Human Research Facility (HRF) rack implemented many noise mitigation applications. The result of these applications helped to reduces the noise produced to levels that were allowable for continuous operations. These efforts additionally allowed for increased intermittent activity.

Melamine foam was applied throughout the interior walls of the HRF rack in addition to installation within the center column between the two sides of payloads. The Melamine foam that was installed on the interior wall was enclosed within a Nomex pouch that allowed for the noise energy to pass through and be attenuated by the Melamine. Within the Nomex pouch, on the side that was directly in contact with the shell of the rack, was installed a layer Bisco to assist with low frequency attenuation.

A foam gasket material was applied to the seat track of the HRF rack and was used to create a seal between the inserted subrack hardware that was operated and the rack. Additional closeout barriers were installed that covered the gaps between adjacent payloads on the front surface. These closeouts on the front face of the rack were created using a material called Strip-N-Stick and adhered with Velcro.

Operational controls within the HRF rack were also evaluated to reduce noise levels. Fan speeds within each of the sub-rack and the rack itself were evaluated at various operational speeds to help determine allowable thermal requirements and acoustic requirements.

7.2 MICRO-GRAVITY SCIENCE GLOVEBOX

The Micro-gravity Science Glovebox (MSG) evaluated many of the same noise mitigation applications that the HRF rack installed. Sound absorbing foam was installed on the interior wall of the rack's skin helping to attenuate some of the sound energy produced.

The Bradford Avionics Air Assembly (AAA) fan and the Glovebox Air Handling Unit (AHU) fans went through a series of modifications resulting in Rotor and Stator modifications and super balancing of the bearings within the fans themselves. The inlet ducting supplying air to the AAA fan was modified to reduce turbulent flow noise that was created by the inlet orifice.

7.3 EXPRESS RACKS AND SUB-RACK PAYLOADS

The Express Racks implemented the use of open cell, sound absorbing foam against the interior skin of the rack. This foam was used in open spaces to attenuate and absorb the noise and sound energy.

Some of the sub-rack experiments that are used within the Express rack facilities exchange air with the cabin to assist in their hardware cooling. These front breathing experiments allow noise to flow from its source without any impedance out into the habitable volume of the Space Station, causing the rack to exceed its noise allocation in many cases. Mufflers that are attached by Velcro to the front face of the sub-rack were developed for these payloads. The mufflers were designed with sound absorbing foams, baffling, and chambers. The foam absorbs noise while the chambers and baffling aid in eliminating the "line of sight" and also provides more surface area for attaching absorbing foam. The mufflers are designed not to restrict any airflow that would result in increased fan load.

7.4 MINUS EIGHTY DEGREE LABORATORY FREEZER INCUBATOR (MELFI)

The MELFI rack used Melamine sound absorbing foam and barrier material that was used to wrap around the engine making noise. Additional sound absorbing foam was installed in front of the rack to lower noise levels. The Melamine foam was encased within a Nomex cloth to help prevent the Melamine foam from particulating due to excessive contact. The Nomex cloth also served as a means for attaching Velcro so as to mate to the rack when installed.

8.0 STATISTICS ON EXCEPTION TO THE PAYLOAD NOISE REQUIREMENT

Most payloads that have required an exception to the noise requirements have had problems in the 250 Hz to 1000 Hz octave frequency bands. This can be seen in the following chart, Figure 8.0-1, Exceedances per Frequency, which was developed from data collected from Stages 6S-8S (1999-2004).

The common problem frequencies shown below are ones that should be avoided when evaluating and selecting fans, pumps, etc.

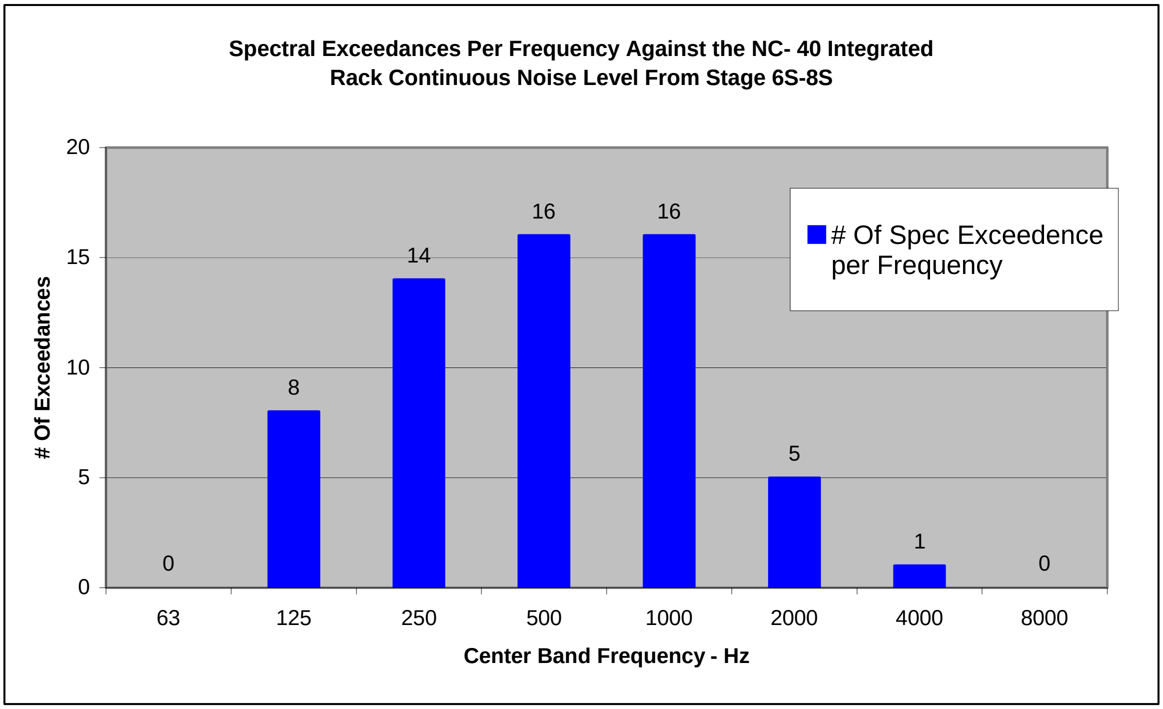


FIGURE 8.0-1 EXCEEDANCES PER FREQUENCY

9.0 FAILURE TO MEET REQUIREMENTS

Hardware that fails to meet the acoustic requirements for continuous and/or intermittent noise operation stated in section 3.2 of this document may be subject to various levels operational constraints. An operational constraint may be in the form of a reduction of time allowed to operate to special time lining so as to not operate when other hardware is operating that consumes significant levels of the allocated noise budget. In addition, an Exception against the failure to meet the specific requirement will be generated.

9.1 EXCEPTION PROCESS

By not meeting the established noise requirements for continuous or intermittent operation a payload developer or rack integrator will need to submit an exception against the specific requirement. This exception shall document the tested noise levels that exceed the requirement and shall document methods that the developer or rack integrator has performed in reducing the overall noise levels.

Once the exception is generated it will be evaluated at various groups and panels (i.e. the AWG, The Astronaut Crew Office, and the Payload Engineering Control Panel to name a few). All of these groups have the authority to disapprove the proposed exception.

9.2 OPERATIONAL CONSTRAINTS

9.2.1 INTERMITTENT

Integrated payload racks are subject to intermittent operational limitations as a function of their A-weighted Overall Sound Pressure Level (OASPL). This OASPL is the level produced by the rack and subrack while operating together. Time limitations are provided in section 3.2 of this document and in SSP 57000 section 3.12.3, Acoustic Requirements. An integrated rack that does not meet the intent of the continuous noise requirement may be subject to intermittent operational time constraints.

9.2.2 CONTINUOUS

Payload hardware and Integrated Racks that fail to meet the requirements for continuous noise and are granted an exception for continuous operation may become subject to an operational time line constraint. The time line constraint is evaluated against the integrated payload continuous noise complement level of NC-48. If a specific complement of payloads exceeded its NC-48 requirement, the operation of one piece of hardware may be moved to an earlier or later time within the stage or increment so that the NC-48 complement level is not exceeded. Refer to section 4.3 within this document.

10.0 VEHICLE NOISE REQUIREMENTS

Vehicle noise requirements limit the continuous noise emissions of ISS vehicle subsystems. The vehicle noise limit is the NC-50 noise criterion shown below in Figure 10.1-1, NC50 Octave Band Noise Criterion. This curve gives the maximum octave band noise level as a function of frequency. This requirement is contained in the top level ISS System Specification, SSP 41000, System Specification for the International Space Station Alpha.

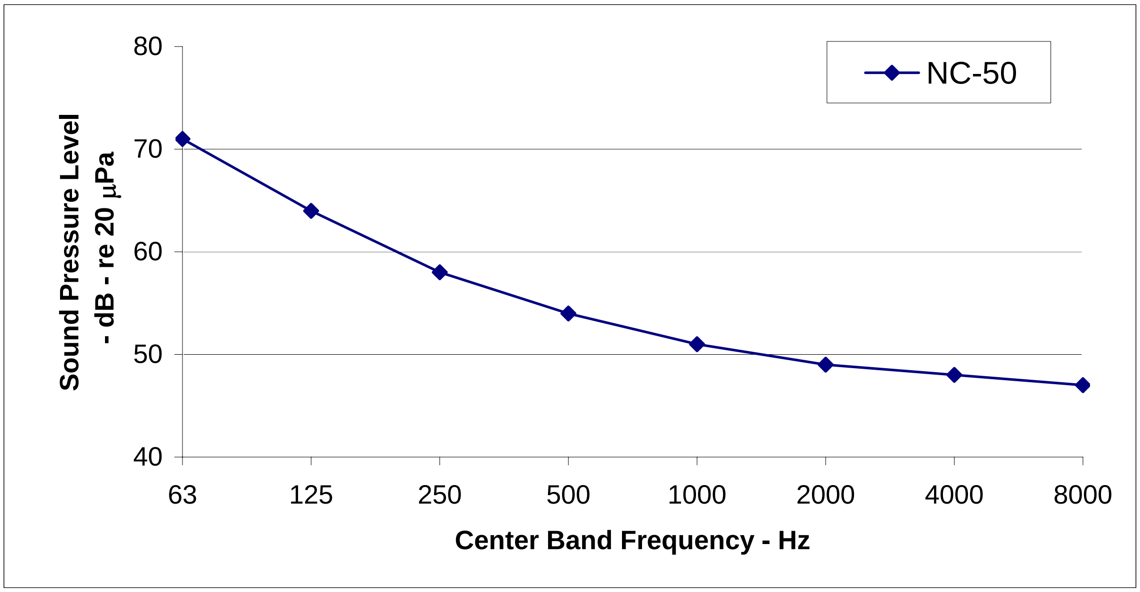


FIGURE 10.1-1 NC50 OCTAVE BAND NOISE CRITERION

The overall NC-50 noise requirement flows down to each Segment contribution from each of the IPs. The NC-50 requirement for each segment, in turn, flows down to the development specifications for each module or flight element. When individual NC-50 modules are joined on-orbit, a uniform NC-50 noise level throughout the combined station will result, assuming previous requirements are met.

A specification tree, Figure 10.1-2, “Flow-Down” Of Noise Requirements from ISS System Specification is used below to illustrate how the noise requirements flow down from the ISS System Specification. In this figure, the overall noise requirement (NC-50) is contained in SSP 41000, the development specification for the International Space Station.

The International Partners collaborating on ISS development have their own ‘Segment’ specifications. The Segment specifications call out NC-50, with the exception of the Russian Segment. Different noise requirements are contained in the Russian Segment Specification. The Russian noise requirements are shown below in Figure 10.1-3, Russian Segment Noise Requirements, as compared to the NC-40, NC-50, and NC-60 criterion.

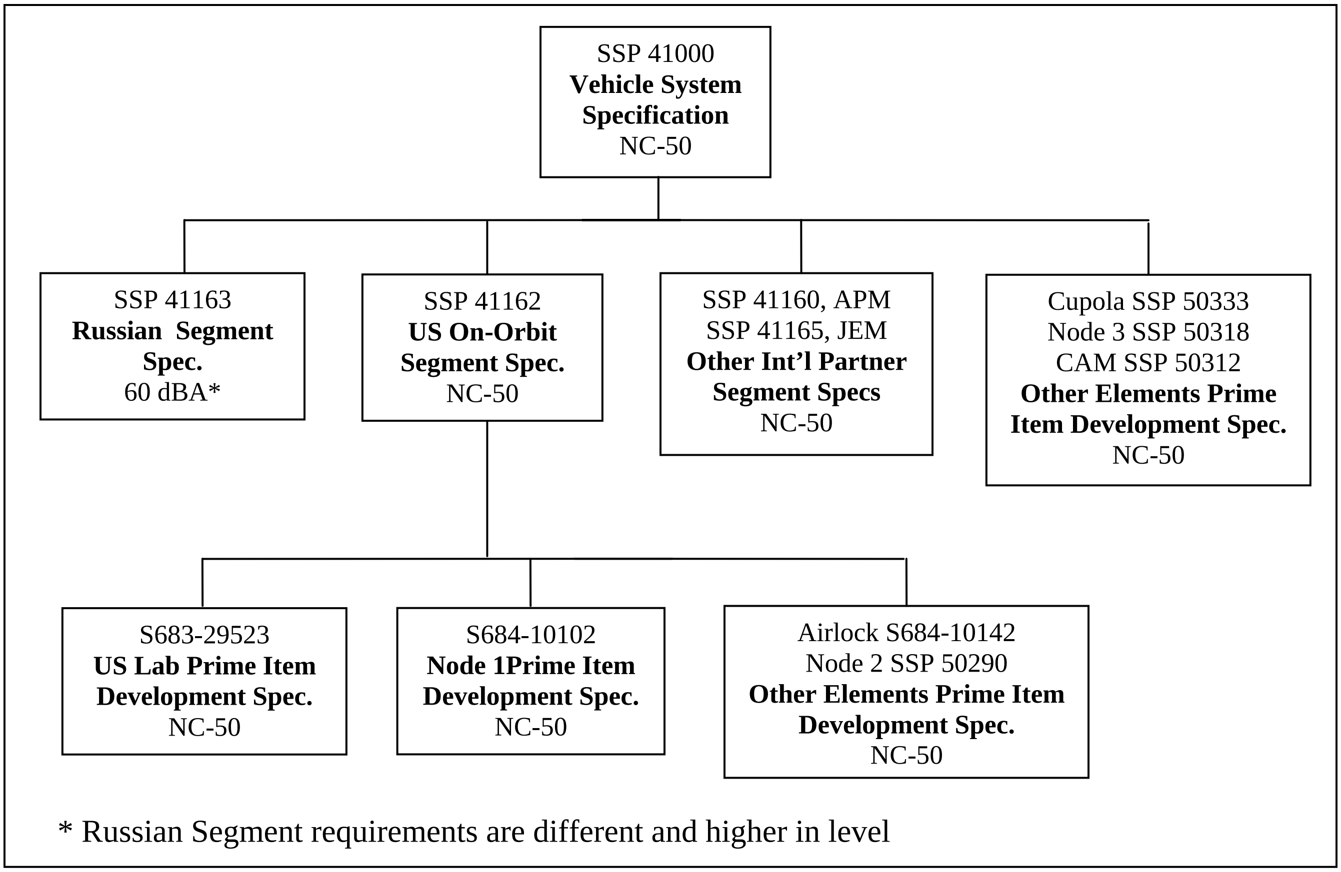


FIGURE 10.1-2 "FLOW-DOWN" OF NOISE REQUIREMENTS FROM ISS SYSTEM SPECIFICATION

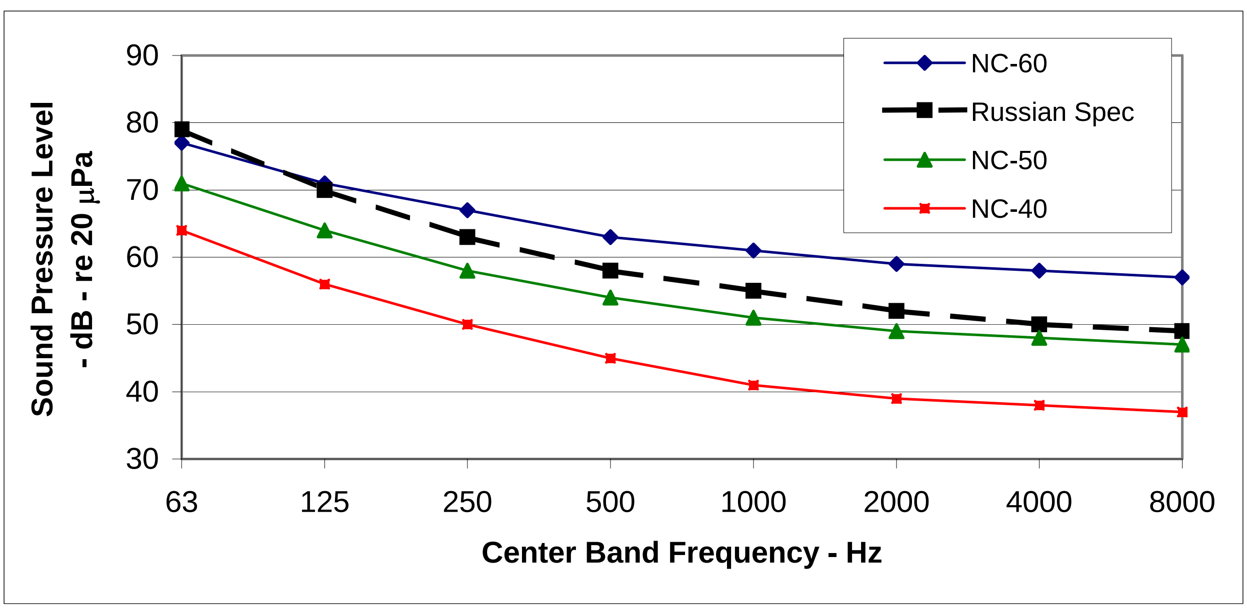


FIGURE 10.1-3 RUSSIAN SEGMENT NOISE REQUIREMENTS

APPENDIX A

ACRONYMS AND ABBREVIATIONS

APPENDIX A - ACRONYMS AND ABBREVIATIONS

AAA	Avionics Air Assembly
AHU	Air Handling Unit
ANCP	Acoustic Noise Control Plan
AWG	Acoustic Working Group
BISCO	Barium Impregnated Silicon Oxide
BPF	Blade Pass Frequency
CDR	Critical Design Review
CFM	Cubic Feet per Minuet
CoFR	Certificate of Flight Readiness
CSA	Canadian Space Agency
dB	decibel
dBA	A-weighted decibel
EXPRESS	Expedite the Processing of Experiments to the Space Station
F	Fahrenheit
GL&C	Guidelines and Constraints
GSE	Ground Support Equipment
H_2O	Water
HEFO	Habitability and Environmental Factors Office
HRF	Human Research Facility
Hz	Hertz
ICD	Interface Control Document
IEHA	Integrated Equipment Hazard Analysis
IP	International Partner
IPIC	ISS Payload Integration Contract
IRD	Interface Requirement Document
ISS	International Space Station
JEM	Japanese Experiment Module
JSC	Johnson Space Center
MAPTIS	Materials and Processes Technical Information System
MELFI	Minus Eighty Degree Laboratory Freezer Incubator
MSG	Micro-gravity Science Glovebox
NASA	National Aeronautics and Space Administration
NC	Noise Criterion
OASPL	Overall A-weighted Sound Pressure Level

PDR	Preliminary Design Review
PEI	Payload Engineering Integration
PICB	Program Integration Control Board
POIC	Payload Operation Integration Center
PSRP	Payload Safety Review Panel
PWL	Sound Power Level
RPM	Revolutions Per Minuet
SPL	Sound Pressure Level
US Lab	United States Laboratory
VES	Vacuum Exhaust System

APPENDIX B

GLOSSARY OF TERMS

(RESERVED)

APPENDIX B - GLOSSARY OF TERMS

APPENDIX C

OPEN WORK

(RESERVED

APPENDIX C - OPEN WORK

APPENDIX D

REFERENCES

APPENDIX D – REFERENCES

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